REALIZATION OF SOME NOVEL ACTIVE CIRCUITS

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SYNOPSIS

Filter is a generic term to describe a signal processing block and is used in various areas such as instrumentation, control systems, communication engineering etc. Filters circuits pass only a certain range of signal frequencies and block or attenuate signal of frequencies outside that band. The application of filters can range from high frequency band pass filters, used in channel selection at the telephone central offices, low pass filter for data acquisition systems, high pass filter for signal separation in the audio amplifier, band reject (notch) filters used for suppression of interfering signals also called as wave traps. Depending upon technology used a possible classification can be as follows: (i) Passive filter, (ii) Active filter, (iii)Digital filter and (iv) Mechanical filter.

Passive filters can be realized by using passive components such as resistors, inductors, and capacitors. These filters can be employed for realization of filters up to 100MHz. Achieving desired gain, input and output impedance may be difficult in the passive filter realization. These filters are not suitable for the integrated circuits realization due to technology limitation in making inductors and high value of resistances and capacitances.

Realization of active filters employs combination of active circuits (Op-amps) and passive elements (resistance and capacitance). These filters can offer high input impedance, low output impedance and ideally any arbitrary gain. But the performances of active filters are limited by the gain-bandwidth (GBW) product of active devices like transistors & Op-amp. These filters are not suitable for very high frequency and high quality factor (Q) applications. These filter circuits are realizable in the integrated circuit.

In digital filters, the input signal is sampled, quantized and then processed for the filtering. Mostly these filters can be realized by delay lines and adders. Due to quantization noise, these filters are noisier as compared to above mentioned filters and the frequency response is limited by the sampling speed.

Mechanical filters are realized by piezoelectric crystal. These filters are suitable from audible range to VHF band applications.

Depending upon the required frequency responses the filters may be classified as: (i) Low pass filter, (ii) High pass filter, (iii) Band pass filter, (iv) Band reject filter and (v) All pass filter.

All these filters can be realized by employing active elements and passive components. Radio, Television, mobile phones, radar, satellite and biomedical equipments are few typical examples of systems that employ active filters [1].

Filters are used for selecting the desired frequency response from a mixture of signals of various frequencies. The steepness and the complexity of the frequency response of the filter depend on the order of the filter. The higher order filter offers higher steepness but their realization is more complex and more expensive to build due to more number of active and passive components. Due to difficulties in the design of higher order filter, it can be realized by combination of first and second order filters. All the basic filter responses (low pass, high pass, band pass and band reject) can be realized by employing second order filter. However, low pass and high pass filter can be realized by first order filter also.

Various topologies for the second order filter such as Sallen-Key filter, Multiple feedback (MFB) filter, Tow-Thomas filter, Akerberg-Mossberg filter, State variable filter, etc, have been employed these topologies employ one or more Op-amps to achieve magnitude and phase response [2-6]. Sallen-Key filter circuit is a simplest filter circuit to design with minimum number of active and passive components. It has orthogonality between quality

factor (Q) and the cutoff/mid frequency (f_c). But the quality factor and gain of the filter are not orthogonal. Multiple feedback filter allows to adjust quality factor, gain and the cutoff/ mid frequency independently. Tow–Thomas filter gives higher quality factor as compared to Sallen-Key and Multiple feedback filter with more number of active and passive components. Akerberg-Mossberg filter offers better phase response as compared to Tow-Thomas filter. All these above mentioned filters offers only one filter responses while State variable filter (KHN) offers three filter responses simultaneously. However, performances of these filter circuit using active circuit (Op-Amp) is limited due to lower gain-bandwidth product and higher supply voltage. Subsequently a number of newly developed active circuits or building blocks have been employed for realizing desired filter responses such as operational transconductance amplifier (OTA), differential difference amplifier (DDA), four terminal floating nullor (FTFN), current conveyors (CC), differential difference current conveyor (DDCC) and dual-X differential difference current conveyor (DXDDCC). Operational transconductance amplifier is Voltage Controlled Current Source (VCCS). It offers high input and output impedance. The internal circuit of the OTA is simpler than the operational amplifier, which provides better bandwidth than conventional Op-Amp. The transconductance of OTA is externally tunable, which helps circuit designer to realize voltage controlled oscillator, filter, amplifier circuit etc. Differential difference amplifier (DDA) is an extension of the conventional Op-Amp. It has four input terminal and one output terminal. The more number of input terminals reduces the number of passive components for the arithmetic operations. The other characteristics of DDA are same as conventional Op-Amp. Four terminal floating nullor (FTFN) is a more versatile building block than Op-Amp and current conveyors. Any active circuit can be realized by the FTFN. It adds the features of the voltage mode and current mode circuits. Current conveyor building block was presented by Sedra and Smith. These circuits offer low power supply and have wider bandwidth, ideally infinite.

Second generation current conveyor (CCII) have found many applications in the current mode and mixed mode filter design, instrumentation and wide band amplifiers and many more. Conventional CCII cannot be used in applications demanding differential or floating inputs like impedance converter circuits and current-mode instrumentation amplifiers. Then the design of such an amplifier requires two or more CCIIs. This problem has been solved with the help of special current conveyors - current conveyors with differential input (DDCC). Differential Difference Current Conveyor building block combines the advantage of DDA and CCII. The Dual-X DDCC building block enhances the capabilities of the DDCC. It helps to realize a resistor less circuit. An effort in this thesis has made to obtain the realization with the recently introduced novel active devices.

This thesis mainly deals with realization and simulation of some second order active filters using conventional and some recently introduced active devices given above. The active devices employed in these filter realizations are conventional operational amplifier, operational transconductance amplifier (OTA), differential difference amplifier (DDA), four terminal floating nullor (FTFN), current conveyors (CC), differential difference current conveyor (DDCC) and dual-X differential difference current conveyor (DXDDCC). The filter realizations may be considered to be novel as most proposed filters having same Q and ω_n available from the realization of biquad structure. Most of these filters possess the Q and ω_n orthogonality property such that tunability may be achieved independently. Efforts have therefore been made to realize some of biquad circuits and waveform generating circuits using newly active devices. The proposed circuits except FDDA are realized on the bread board and also simulated by PSPICE software. The proposed circuit using FDDA was simulated on the PSPICE. The results and performance of the proposed circuits match the design specifications.

SCOPE OF THE THESIS

The thesis is presented in seven chapters. The chapter wise contents of the thesis are discussed as follows.

CHAPTER 1

The Chapter-1 deals with the introductory overview including historical development of the active devices. The basic filtering problem using Op-Amp and types of the active devices used have been discussed in this chapter. The circuits realized by the zero pole model and one pole models of the Op-Amps are also studied [7-10]. Active-R and Active-C realizations of Op-amp based circuits are discussed [11-13]. The newly proposed circuits using some novel active elements and their performances have been discussed in subsequent chapter of the thesis. The performance analysis of novel active realizations in terms of cut off/centre frequency, bandwidth/quality factor, sensitivity to parameter variation, numbers of passive components and their spread are analytically found.

CHAPTER 2

Chapter-2 is devoted to the realization of some novel active circuits by transconductance amplifiers. The transconductance amplifier can be realized by widely used device Op-Amp and specially designed OTA. For realizations of two active filter responses are obtained from two circuits employing single Op-Amp. The first circuit realizes first order lowpass - highpass response and the second one realizes second order highpass-bandpass filter response. The quality factor Q of the second filter realization is low. The low value of Q is used in systems for which damping is important such as image frequency rejection, for lower bass in audio systems etc. It can be used at the first stage of cascaded filter. All the proposed realizations have low sensitivity to parameter variations.

Applications of Op-Amps as transconductance amplifier are limited. Electronically controlled applications, variable frequency oscillators, filters and variable gain amplifier stages, are more difficult to implement with standard Op-Amps. In view of inherent tunable capability, the operational transconductance amplifier (OTA) is extensively used as a basic active device in many applications as compared to conventional Op-Amps. It can be used for the realization of mathematical operations and logical operations, comparators, integrators, negative impedance , inductor, super inductor and wave form generators [14-22]. The internal circuit diagram of OTA is simpler than operational amplifier due to less active devices (BJT or MOSFET); hence higher bandwidth can be obtained. First in this chapter we present the various developments in the realizations of the active filters employing Op-Amps, the performance of the filter realizations employing zero-pole model and one-pole model of Op-Amp. Next, the chapter focuses realization of two transconductance filters using single Op-Amp. First transconductance filter circuit employing three passive components- one capacitor and two resistors simultaneously realizes low pass-high pass transconductance filter responses. Whereas second circuit realizes high pass-band pass transconductance filter with two resistors and two capacitors. The cutoff /center frequency ω_0 is to be tunable by the changing the values of the passive components and is independent from the open loop gain of the operational amplifier. The realizations have low sensitivity to highly variable and sensitive parameter A (gain–bandwidth product) and employ minimum number of passive components. Subsequently the chapter presents the basic operation of OTA along with its CMOS model, realization of the waveform generator and low-pass elliptical filter circuits using OTA. The realizations of waveform generators are based on OTA LM13700. Various waveform generators employing OTA, reported in the literature, realize individual waveforms such as sinusoidal waveform, square and triangular waveforms. In the literature no single wave-shaping circuit appears to have been reported for realization of more than two different

waveforms at a time. The proposed single waveform generator circuit realizes square, triangular and sinusoidal waveforms simultaneously. The oscillation frequency is linearly varies with the bias current of OTA.

Efficient anti-aliasing is one of the main requirements in the video signal processing circuits. These filters are used before the analog to digital convertors (ADC) to attenuate the signal above the Nyquist frequency. A low sensitivity doubly terminated seventh order LC circuit is simulated. Since inductors are not suitable for in the integrated circuit. The properties of inductors can be realized by OTA and capacitor. Thus complete circuit can be realized using OTAs. The proposed elliptical circuit is resistorless, which saves lot of area in the IC fabrications. In the fabrication the active as well passive components of the circuits have tolerances, It may change the cutoff frequency of the filter, it can be tuned externally by the bias current of the OTA.

CHAPTER 3

Chapter-3 presents the realization of second order active low pass, high pass and band pass filter using fully differential difference amplifier (FDDA). Differential difference amplifier (DDA), an extension of Op-Amp, offers very high input impedance and low output impedance. It has two differential pair of input terminals and one output terminal. The fully differential difference amplifier is a balanced output differential difference amplifier. It provides low output distortion and high output voltage swing as compared to the DDA [23-26]. The filters realized with FDDA possess attractive features that do not exist in both traditional (discrete) and modern fully integrated Op-Amp circuits [27-28]. However the frequency range of operation of FDDA is same as that of the Op-Amps. The FDDA is a circuit element similar to the OTA at the input side and to the Op-Amp at the output side. It can therefore be used for designing DDA-based circuits, with useful properties of both OTAs

and Op-Amps. That is, the circuits designed with FDDA have high input impedance, low component count, low output impedance and low distortion. Thus, the filters realized with FDDA, although operating in the frequency range of Op-Amps possess attractive features such as floating output, less output noise, that do not exist in both traditional (discrete) and modern fully integrated Op-Amp circuits.

The proposed filters possess orthogonality between the cutoff/central frequency and the quality factor. In view of the orthogonality property, the proposed circuits have wide applications in the instrumentation, control systems and signal processing. All the filter realizations have low sensitivity to parameter variations. The first two sections of this chapter present the implementation of DDA and FDDA. Subsequent sections are devoted to the realization of proposed filters and main results. The proposed circuits offer a low quality factor response, which is desirable for the audio signal processing. Absence of even harmonics and higher output swing makes it useful for audio application. In the all proposed realizations, sensitivity of cutoff frequency and the quality factor are less than 1 to passive components variations.

CHAPTER 4

Chapter-4 deals with the realization of a multifunction biquad filter using Four Terminal Floating Nullor (FTFN), a new current mode device. The concept of FTFN has been introduced as a combination of nullator and the norator[29-30]. FTFN can act as ideal amplifier. Two biquad filters having high input impedance have been realized with single input and two outputs simultaneously. It can be used for the realization of analogue circuits[31-40].The filter circuits proposed in this chapter simultaneously implement high-pass and band-pass filtering functions. Each circuit employs two FTFN, two capacitors and two resistors which is the absolute minimum requirement for a biquad filter. By slight modification in the topology of the circuit band-pass and low-pass responses can also be

realized at the same output terminals. Further, the proposed circuits employ lesser number of passive components than the one reported by Liu and Yung [35].

The proposed circuits do not impose any component matching constraints for the filter realizations. It offers orthogonality between the bandwidth and cutoff frequency/ quality factor of the filter. The proposed circuits have low sensitivity figures i.e. less than 0.5. The mathematical analysis with non linear FTFN is also performed. Analytically it is found that the current and voltage tracking error of the non ideal characteristics of the FTFN does not affect the sensitivity of the quality factor and the cutoff frequency.

CHAPTER 5

In Chapter-5 current conveyor proposed by Sedra and Smith is discussed [41]. This building block is popular among the analogue circuit designer to its inherent property of wider band width, lower supply voltage and high speed. Employing current conveyor various active circuits have been reported in the literature [42-53]. In this chapter two circuit configurations are proposed for realizing all five filters with minimum number of current conveyors and passive components. The first circuit employs two balanced current conveyors and six passive components. This circuit has high input impedances and realizes filters with orthogonality in between quality factor and cutoff/central frequency and low sensitivities to parameter variation. The second circuit realizes a multifunction filter using two current conveyors, one OTA and six passive components. The second circuit is a modified version of the first circuit. The second circuit is on-chip tunable. The circuit provides more number of filter realizations at the single output terminal and does not have any matching constraint/cancellation conditions. Further, it is suitable for IC fabrication as it employs grounded capacitor. The realization is orthogonally tunable between the cutoff frequency and the bandwidth. The cutoff frequency of the filter varies linearly with the bias current with a constraint bias current

of the OTA should be higher than the output current. The sensitivities figures of the circuit for active and passive components are less than 1.

CHAPTER 6

Chapter-6 deals with the two new current mode devices, differential difference current conveyor (DDCC) [54-59] and dual-X differential difference current conveyor (DXDDCC). The applications of DDCC and DXDDCC are also discussed in this chapter. DDCC is used to realize a notch filter, while DXDDCC is used for the realization of universal filter. These circuits offer high input and output impedances, low sensitivity to parameter variations. A Notch filter is realized using single DDCC and two resistors and two capacitors with a component spread of two with a constraint of parameter matching.

DXDDCC is an extension of DDCC having on chip-tunability [60]. By employing the DXDDCC a universal filter is proposed with a minimum number of passive elements. It requires two DXDDCC, two MOSFET along with two capacitors. These capacitors are grounded and the proposed circuit is resistorless, which make easier for realization in the integrated circuits with lesser area. The sensitivity of the proposed circuit is 0.5. The circuit has the following features: on chip automatic tuning of cutoff frequency, realization of all filters, less passive components, low sensitivity, ω_0 and Q are orthogonally adjustable.

CHAPTER 7

Finally, Chapter 7 presents the main contributions of the thesis and scope of further work.

Main Contributions:

This thesis presents realization of second order filters employing conventional Operational amplifier, Operational transconductance amplifier (OTA), Differential difference amplifier (DDA), Four terminal floating nullor (FTFN), Current conveyors (CC), Differential difference current conveyor (DDCC) and Dual-X differential difference current conveyor (DXDDCC).

The realized filters show the orthogonality in between the quality factor and the central/cutoff frequency. Sensitivity analysis of the cutoff/central frequency and quality factor with respect active and passive components has been done. Non-linear performance of the active building block has been also studied. Current controlled Sine-Square-Triangular waveform generator circuit and the 7^{th} order elliptical filter have been realized by employing OTA. These circuits have the on- chip tunability. Most of the proposed circuits realize many filter responses simultaneously.

Scope of the further work

Further work can be done in the following areas:

(i) An effort may be made in future to study the effects of stray capacitors and temperature dependence of the devices on the response of the circuits.

(ii) Some other topologies such as Multi Feedback, Tow-Thomas may be studied for the realization of high Q filters using newly proposed active devices.

(iii) Further efforts may be made to design various tunable multifunction filters and oscillator circuits using Current Differencing Transconductance Amplifier (CDTA), a newly developed versatile current mode device. The output current in the CDTA is a function of the input differential current and the output current gain is tunable.

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Research Paper contributions in the thesis:

International Journal

1. Manish Kumar, Umesh Kumar and M. C. Srivastava , "Current Conveyor Based Multifunction Filter" International Journal of Computer Science and Information Security, vol. 7, no. 2 , pp. 104-107, 2010.

2. Manish Kumar, Umesh Kumar and M. C. Srivastava, "Tunable Current Conveyor Based Multifunction Filter", International Journal of Computer Science and Information Security, vol. 8, no. 1, pp. 95-98, 2010.

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International/National Conferences

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